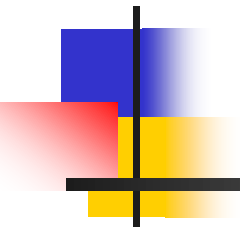
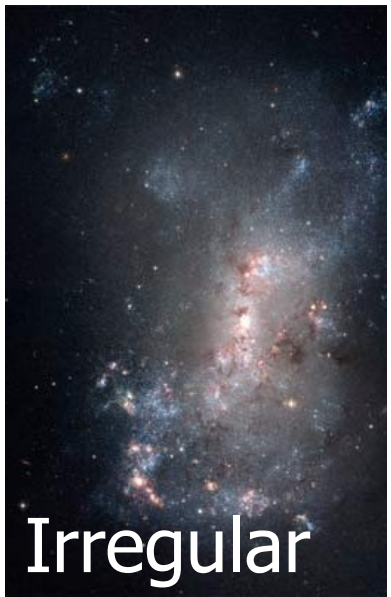


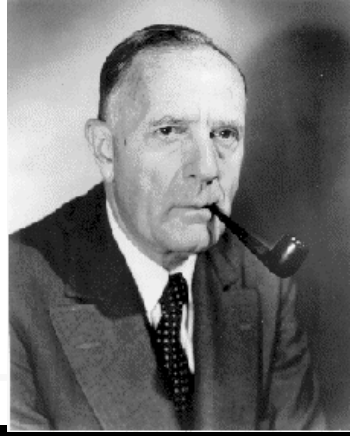
The Present, The Past, And The Future of The Milky Way

The World of Galaxies

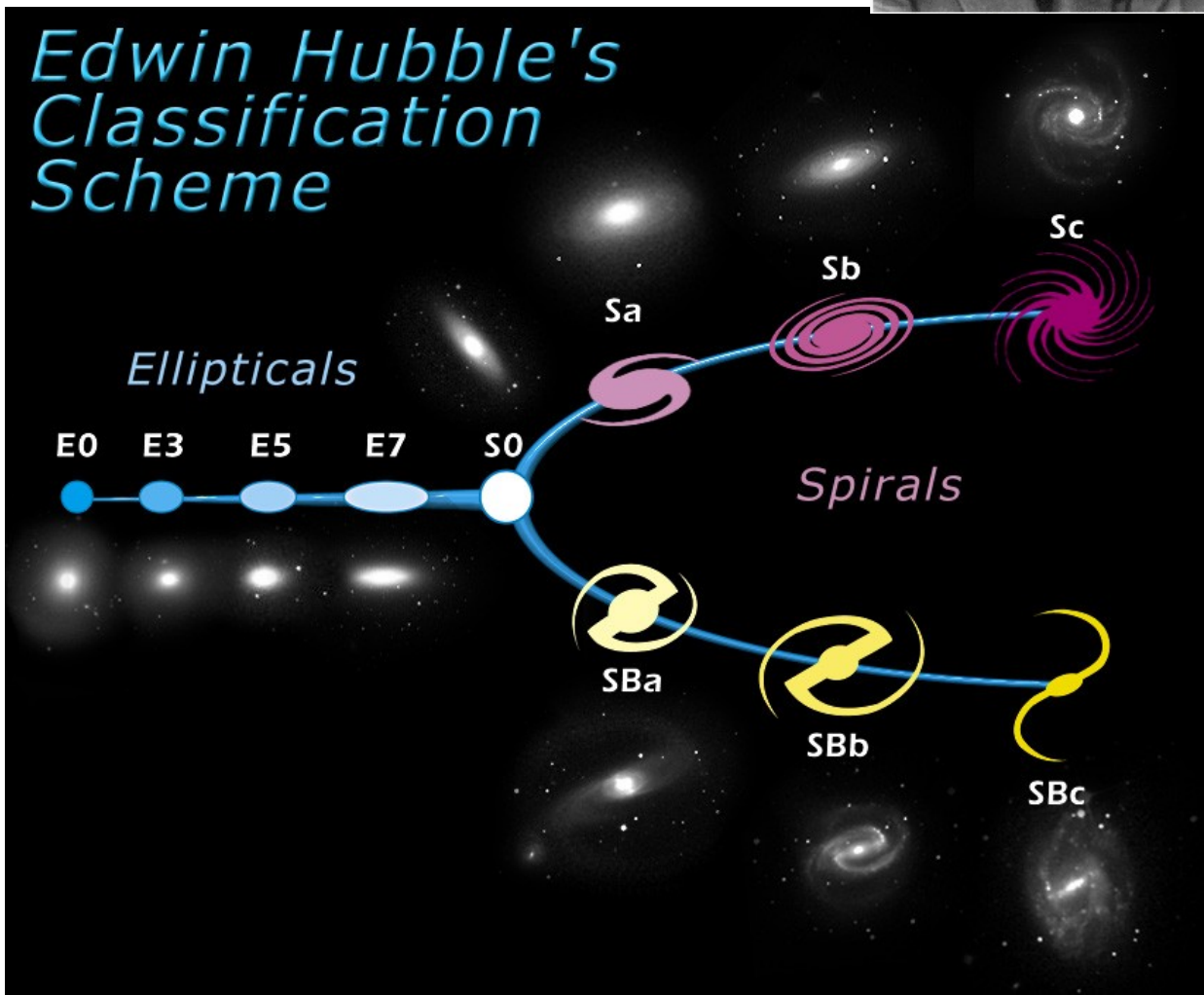
- Galaxies come in three main types:
  - Spirals (like the Milky Way and Andromeda)
  - Ellipticals (they mostly live in large clusters)
  - Irregular (often small, look like mess)



Hubble's Classification



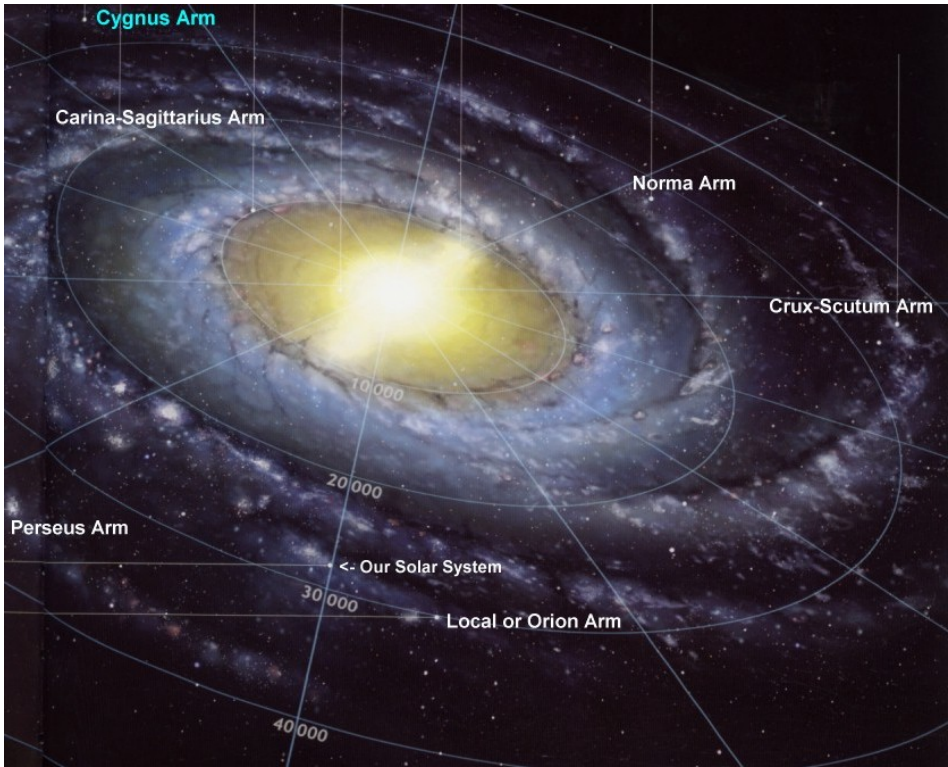
- Edwin Hubble developed a classification scheme that is still in use.
- Many spirals have ***bars*** – the Milky Way has too.



The Milky Way Bars

A bar ***in*** the Milky Way

A bar ***of*** the Milky Way



Galaxy Evolution In Quizzes

- Hubble classification is thought to reflect the evolution of galaxies. Ellipticals are called ***early type***, and spirals are called ***late type*** galaxies.
- The bulges of spiral galaxies look exactly like elliptical galaxies. So, structurally, a spiral galaxy is an elliptical galaxy with a disk.
- Which way does the evolution go?
  - **A**: Elliptical galaxies evolve from spiral galaxies by losing their disks.
  - **B**: Spiral galaxies evolve from elliptical galaxies by growing a disk.

Review Question

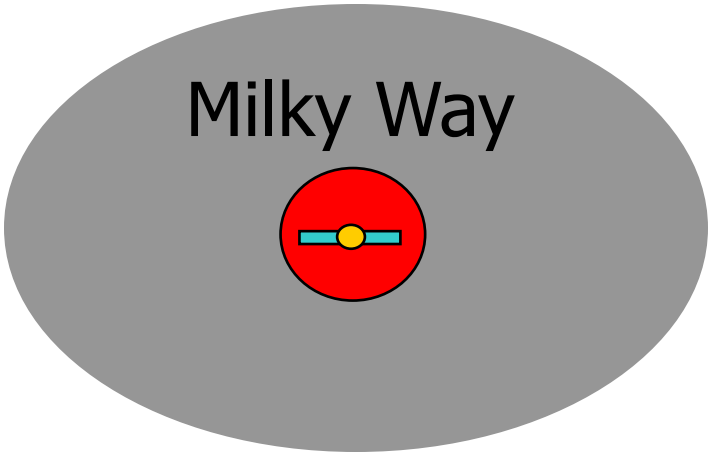
- What are the 3 main constituents of the Milky Way?
  - **A**: gas, dust, stars
  - **B**: dark matter, stars, gas
  - **C**: planets, stars, nebulae
  - **D**: milk chocolate, corn syrup, sugar

Galaxy Evolution Fact I

- The key to galaxy evolution is the different dynamics of dark matter, stars, and gas.
- Dark matter ***always*** forms a quasi-spherical halo, for ***all*** galaxies.
- Gas ***always*** forms a disk, because it…
  - **A**: always keeps cooling.
  - **B**: gets compresses by dark matter.
  - **C**: contains cosmic dust.
  - **D**: glows in the dark.
  - **E**: forms stars.

Galaxy Evolution Fact II

- Dark matter does not cool (by definition!). The "gas of stars" does not cool too (star collide very rarely).
- Stars form from the gas, so young stars are always located in the
  - **A**: stellar halo.
  - **B**: bulge.
  - **C**: disk.

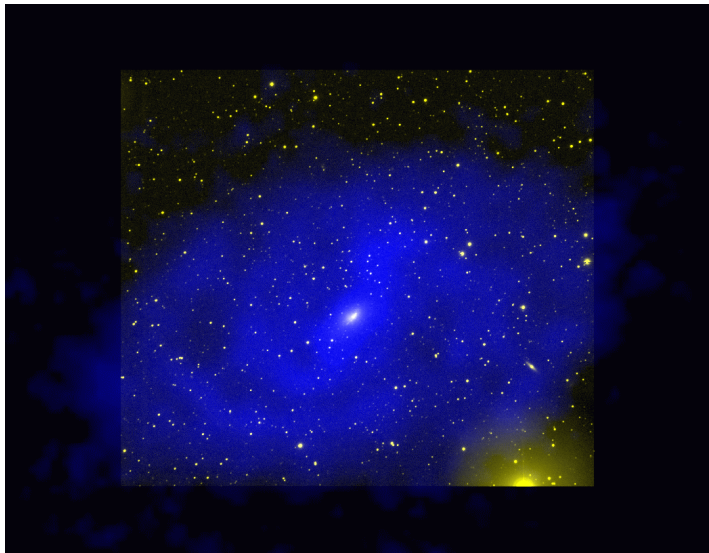


Galaxy Evolution Fact III

- When galaxies collide (merge), orbits of stars in the disk get disrupted and randomized. The "gas of stars" gets "heated", stars turn into a bulge (= elliptical galaxy).
- What happens when two bulges (or two elliptical galaxies) collide and merge?
  - **A**: Stars "cool off" to form a disk.
  - **B**: Nothing happens, just a bigger bulge forms.
  - **C**: A stellar halo forms – the energy of collision "heats" the bulges.

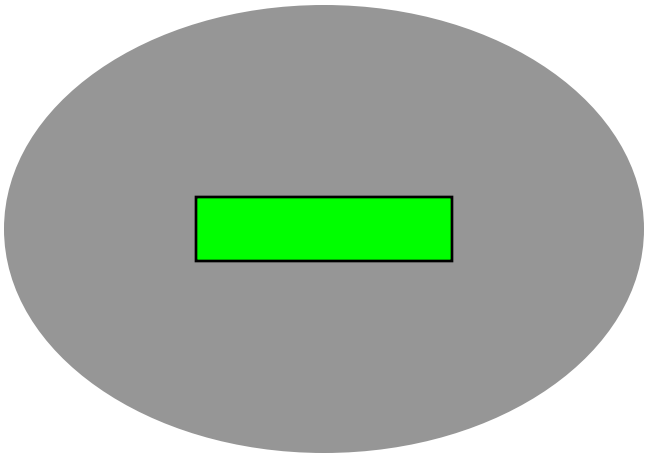
Galaxy Evolution Fact IV

- The first galaxies must be
  - **A**: large, made mostly of stars (and DM).
  - **B**: small, made mostly of stars (and DM).
  - **C**: large, made mostly of gas (and DM).
  - **D**: small, made mostly of gas (and DM).
- Dwarf galaxies today should resemble the early "building" blocks of larger galaxies.
- Indeed, they are mostly gaseous disks.



Galaxy Evolution: Cartoon

- Baby Milky Way: just a gas disk (DM is always there; an edge-on view).



Dark matter

Gas

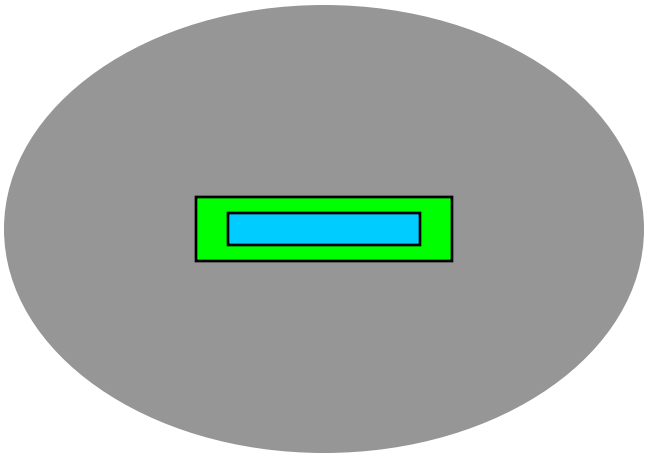
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- Young stars form in the gas disk.



Dark matter

Gas

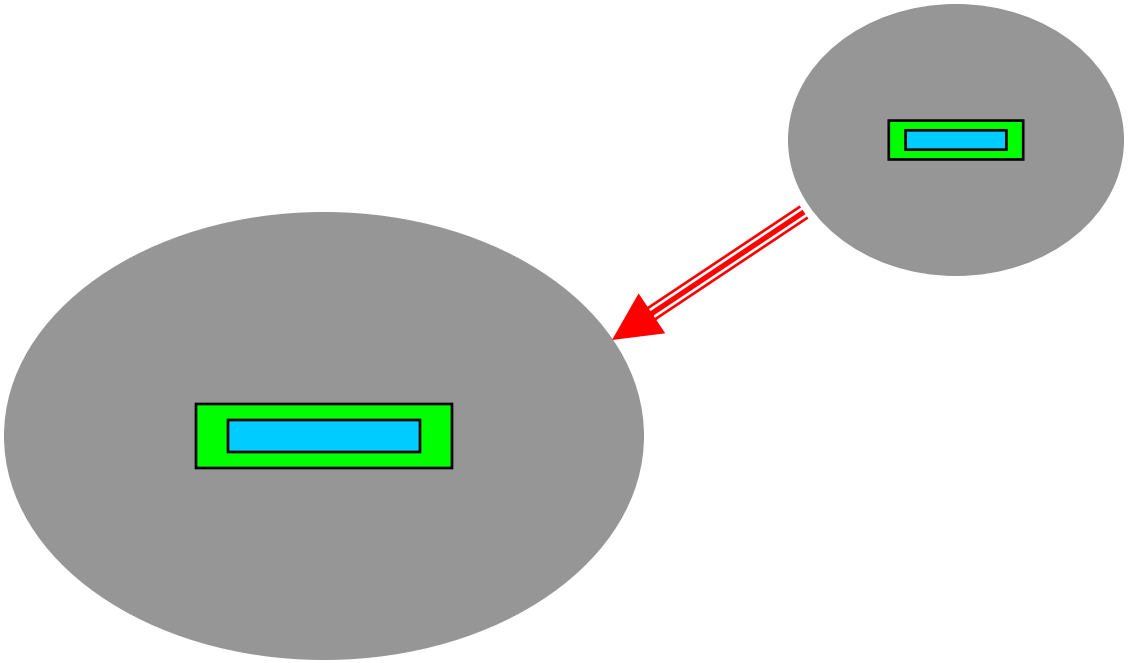
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- We merge with someone else.



Dark matter

Gas

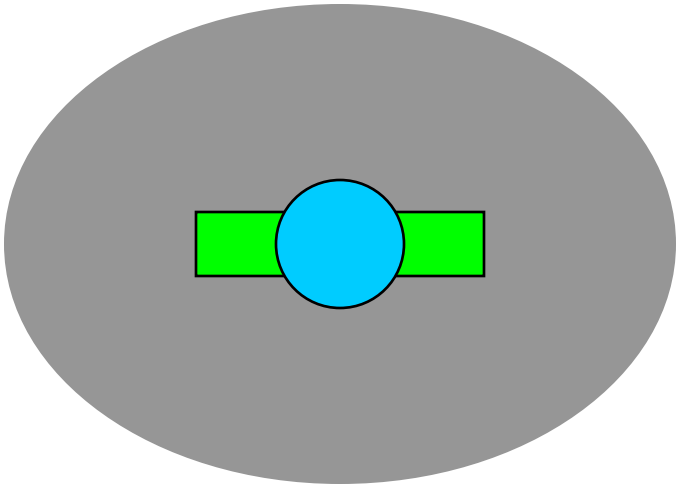
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- Two stellar disks crash into each other, forming a bulge. Gas disk reforms rapidly.



Dark matter

Gas

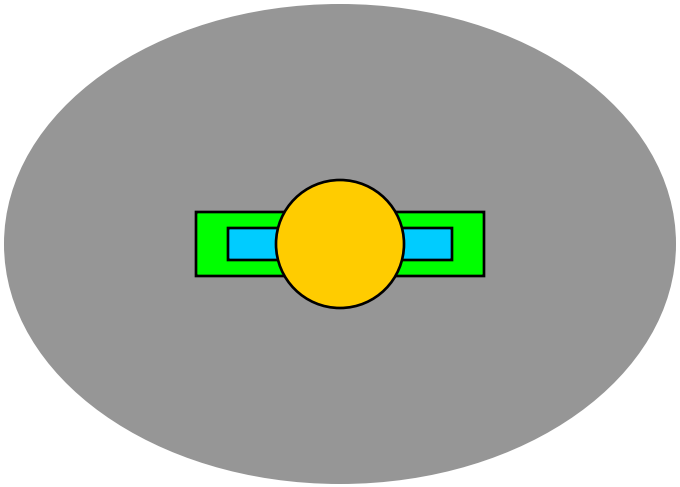
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- Bulge ages, new stars form in the gas disk.



Dark matter

Gas

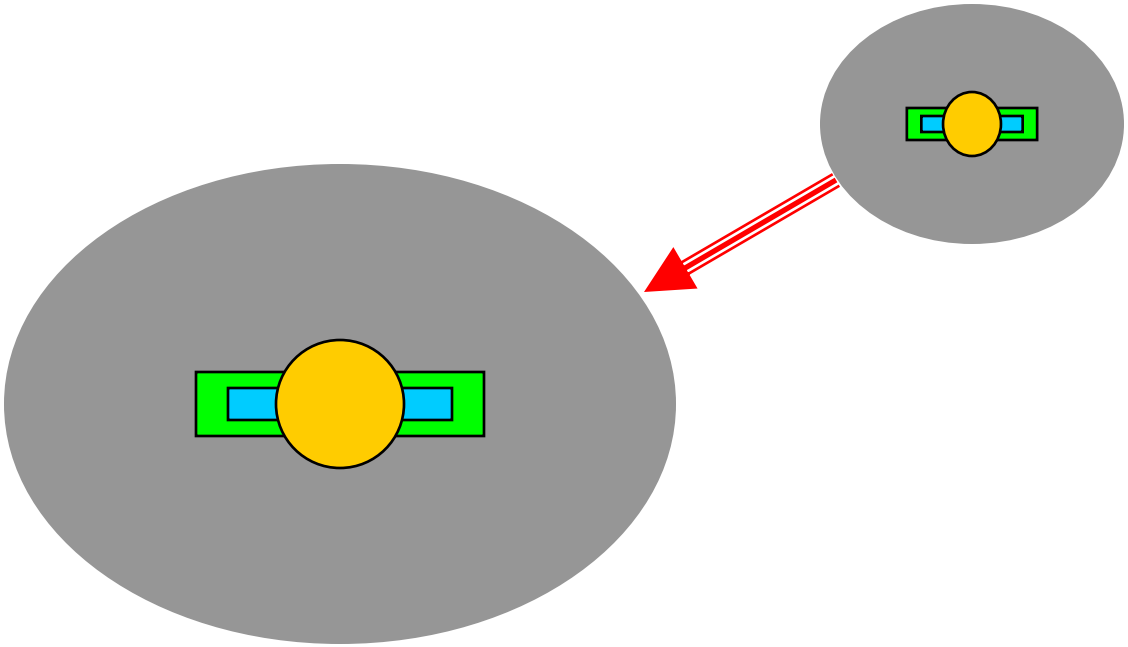
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- We merge with someone else again (last time: about 10 Gyr ago).



Dark matter

Gas

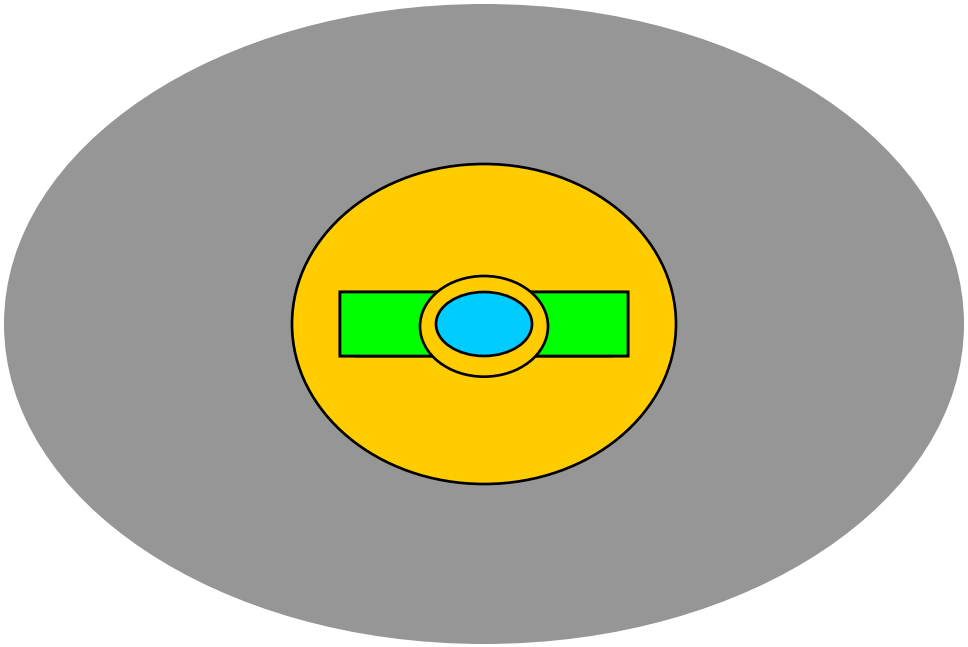
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- Stellar halo forms from collided bulges; younger stars added to the bulge.



Dark matter

Gas

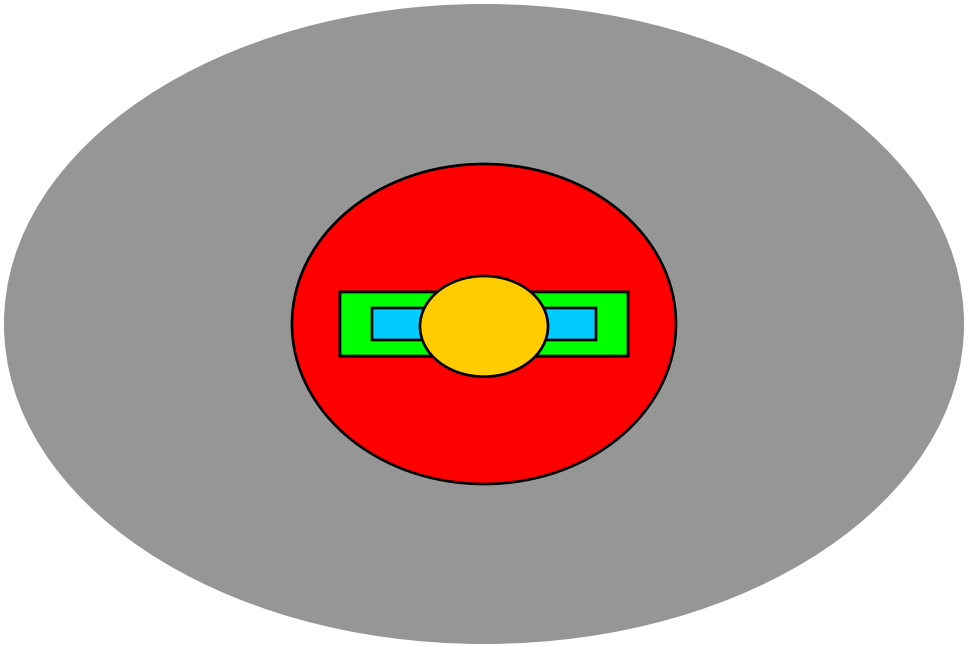
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- Stellar halo and bulge age; new stars form in the gas disk. Here we are!



Dark matter

Gas

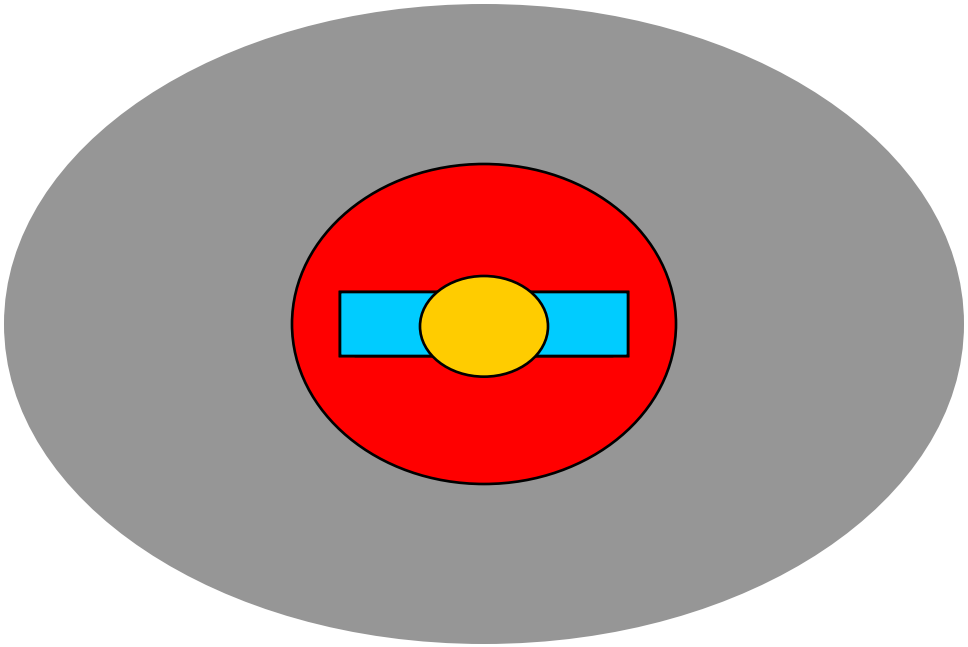
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- Keep going: in about 2Gyr we will consume the rest of our gas.



Dark matter

Gas

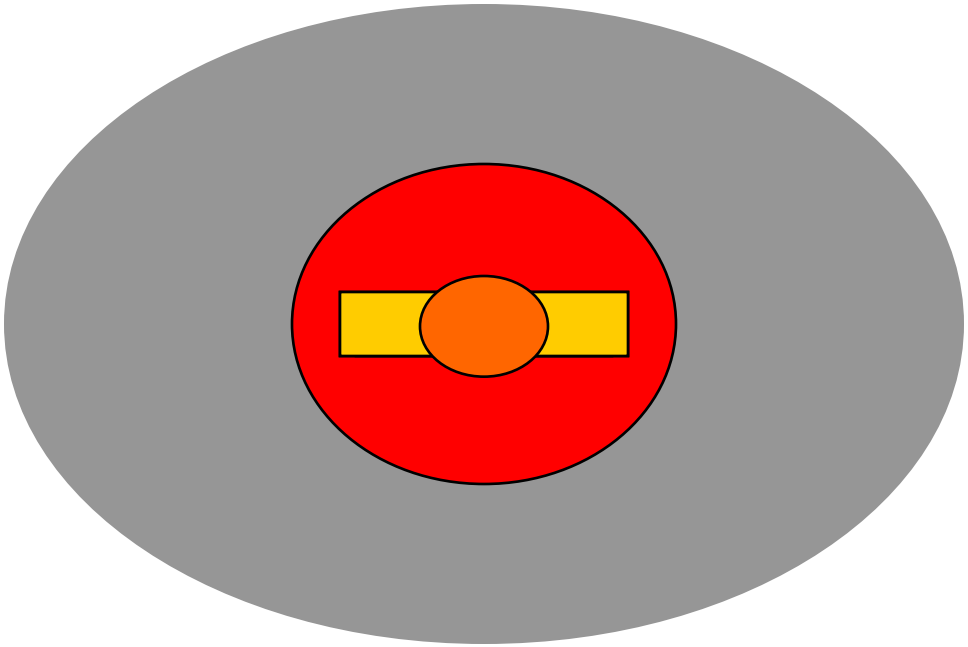
Young stars

Old stars

Oldest stars

Galaxy Evolution: Cartoon

- Disk stars will quickly age.



Dark matter

Gas

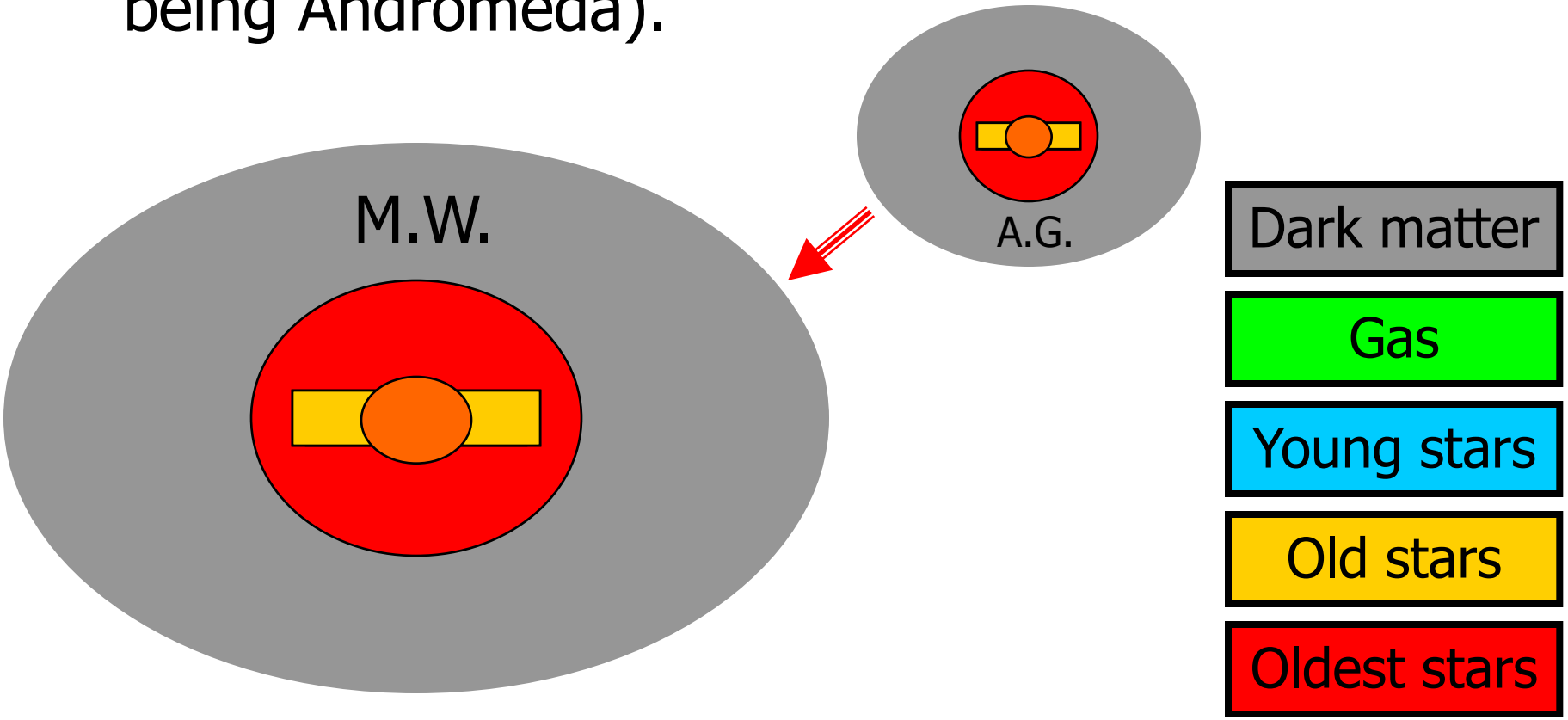
Young stars

Old stars

Oldest stars

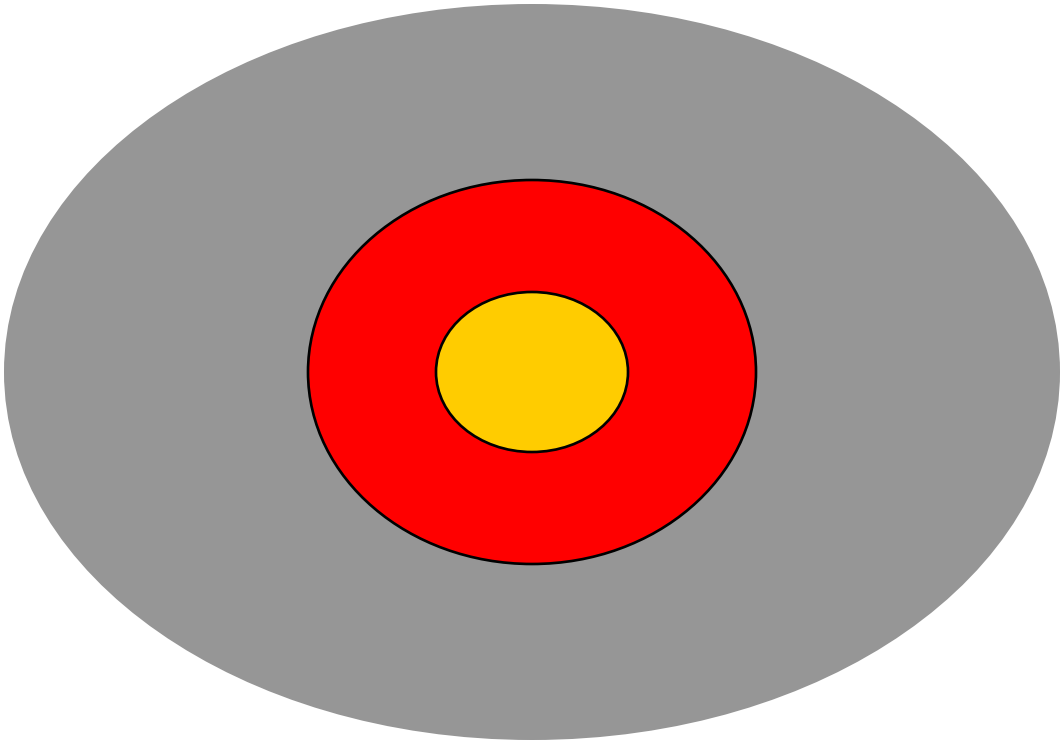
Galaxy Evolution: Cartoon

- We will then collide with something (something being Andromeda).



Galaxy Evolution: Cartoon

- Local Group will become a ***fossil group*** (a group with a single large elliptical galaxy).



Dark matter

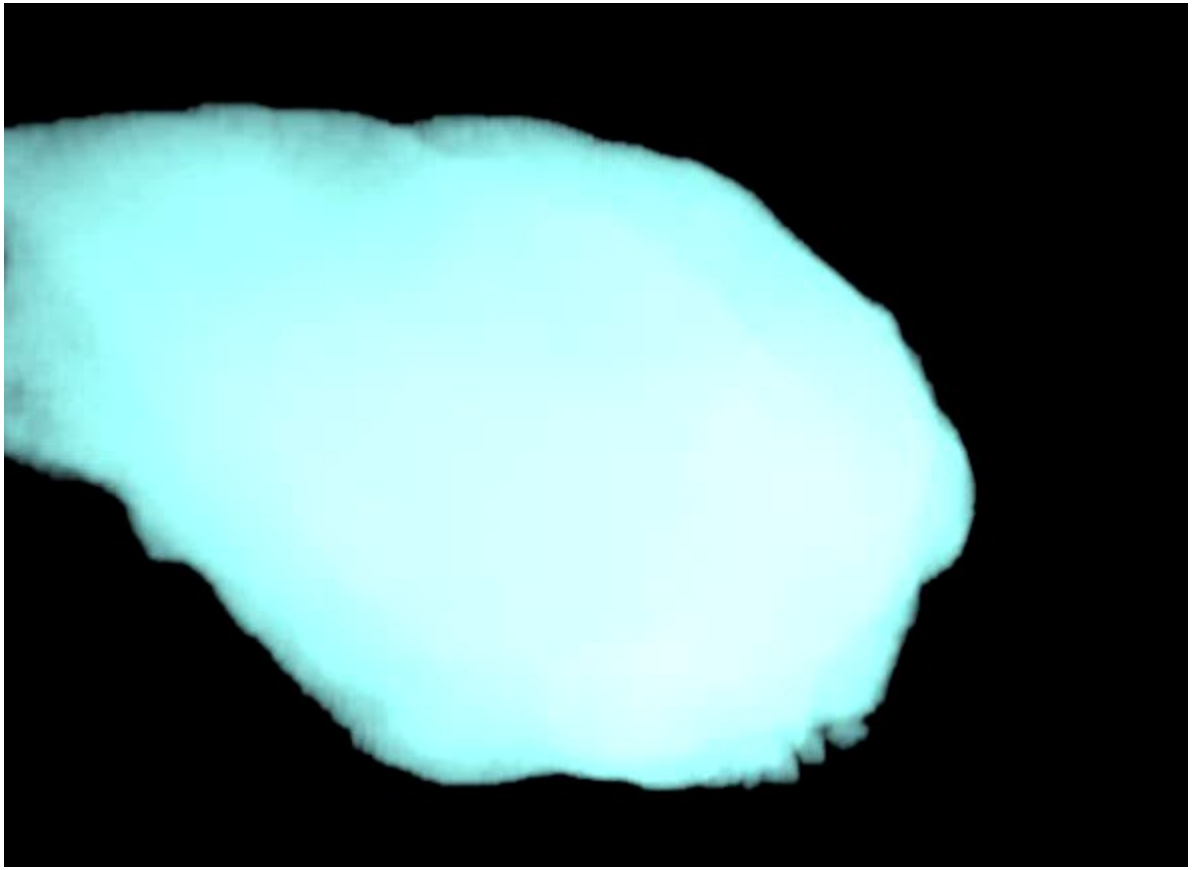
Gas

Young stars

Old stars

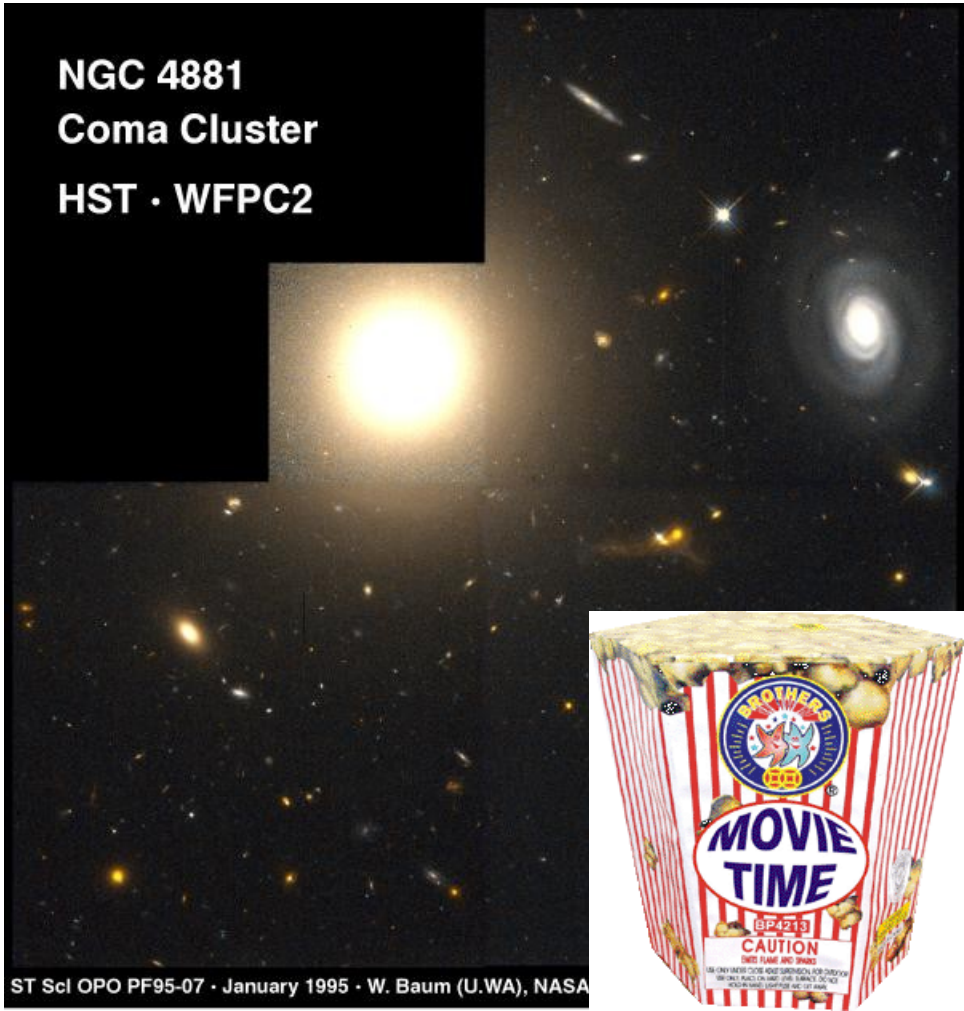
Oldest stars

Milky Way Movie



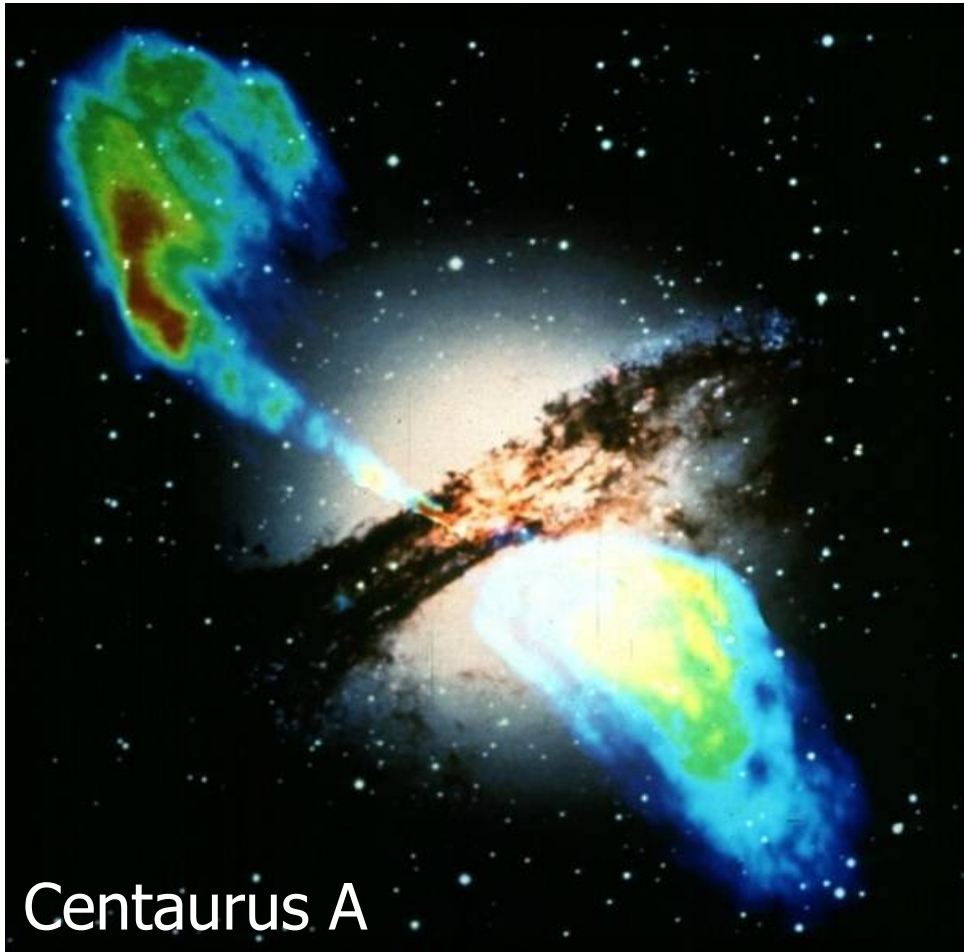
Brightest Cluster Galaxies

- Biggest galaxies are central ellipticals in clusters of galaxies. They can be 30 times more massive than the Milky Way.



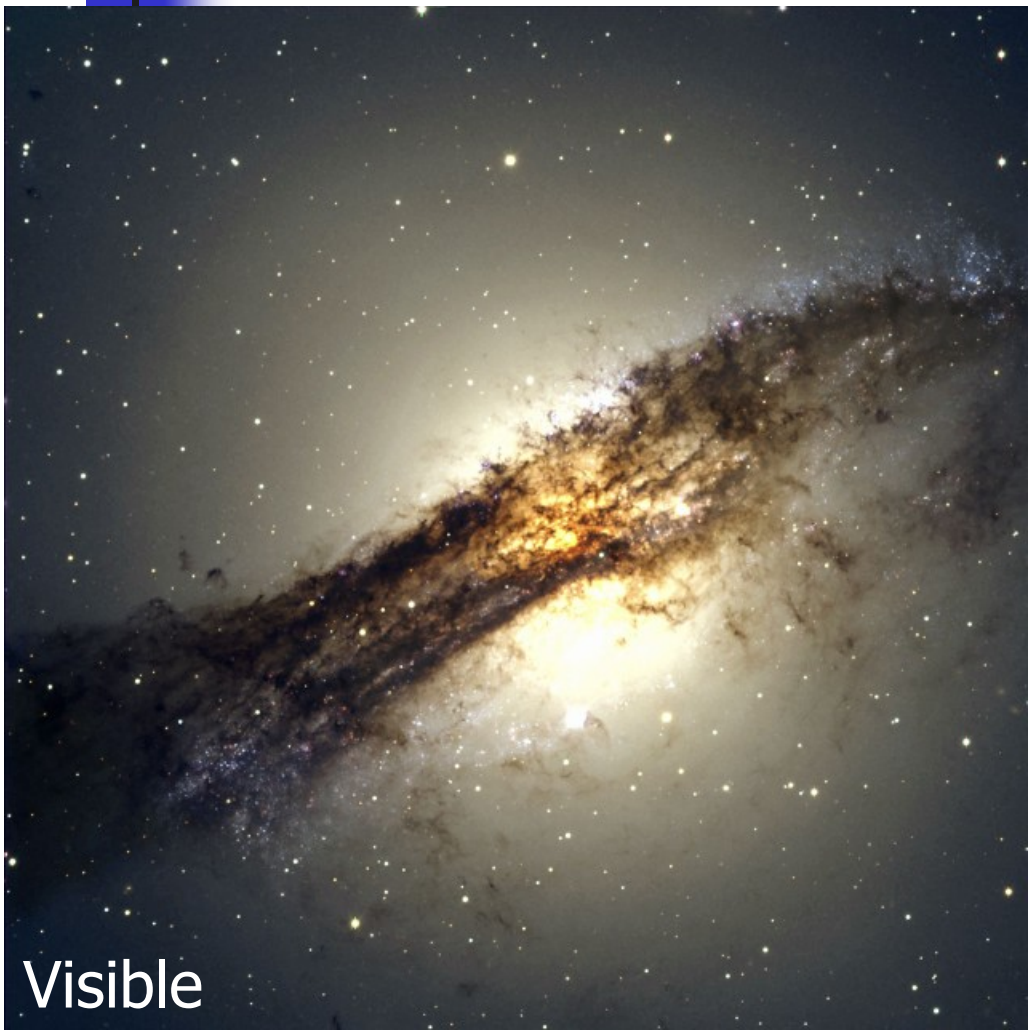
Active Galactic Nuclei

- Many galaxies have active nuclei, with jets, X-ray and gamma-ray emission.
- Spectral lines show large Doppler shifts, indicating velocities up to 10 - 20% of the speed of light.



Centaurus A

Centaurus A


Visible

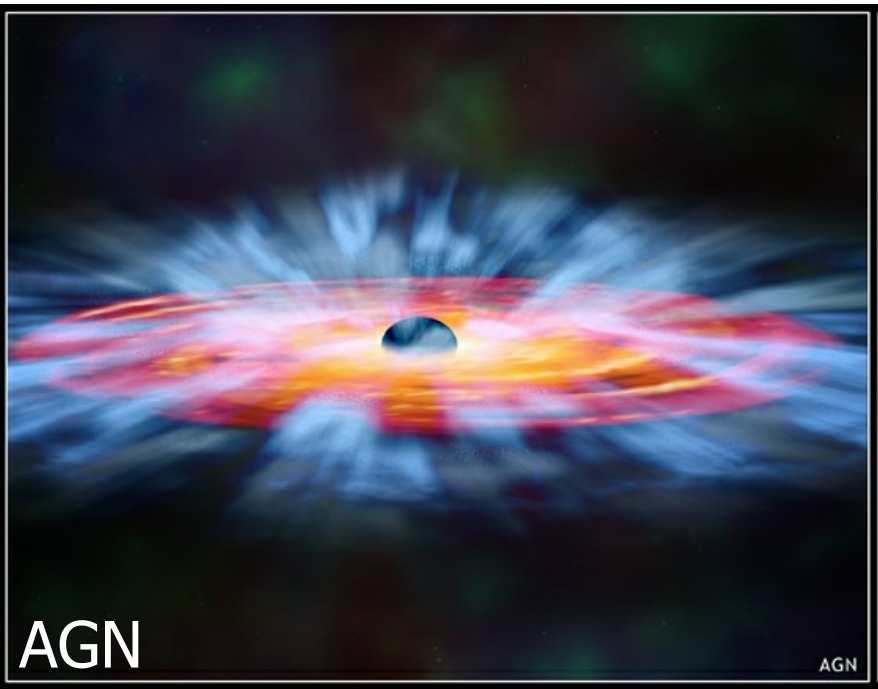

The peculiar radio galaxy Centaurus A
Near infrared

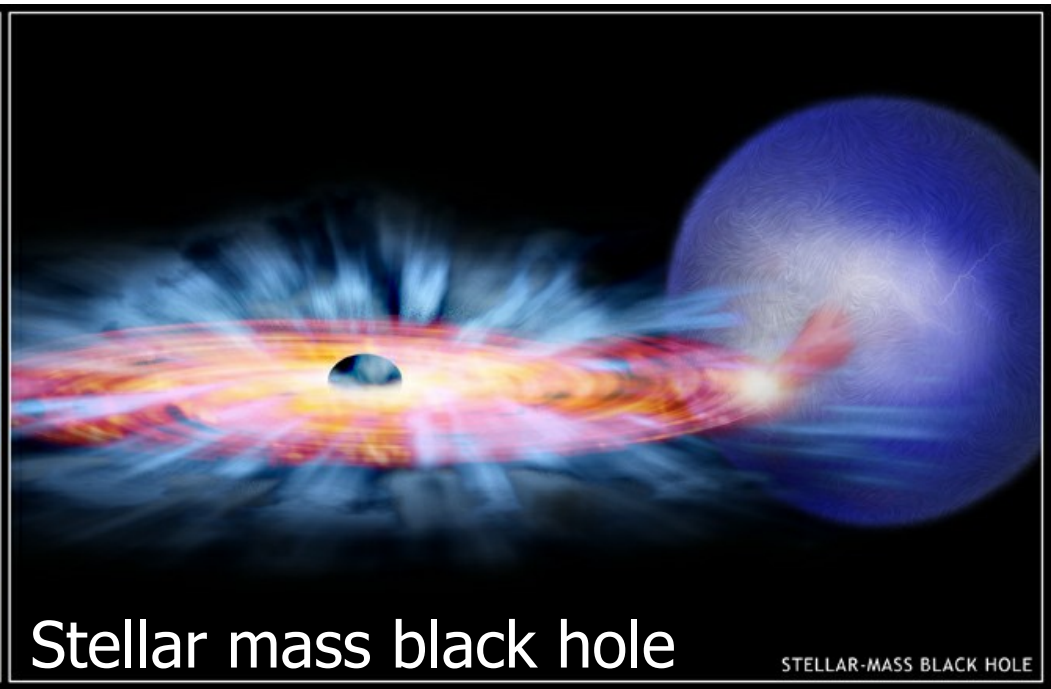
Question

- What could be the source of energy for such violent activity?
  - **A**: a supernova
  - **B**: a black hole
  - **C**: an interstellar nuclear war
  - **D**: large number of supernovae in a small region of space

Quasars

- There are many types of AGN: DRAGNs, Seyfert galaxies, quasars.
- ***Quasars*** are the most powerful of AGN.



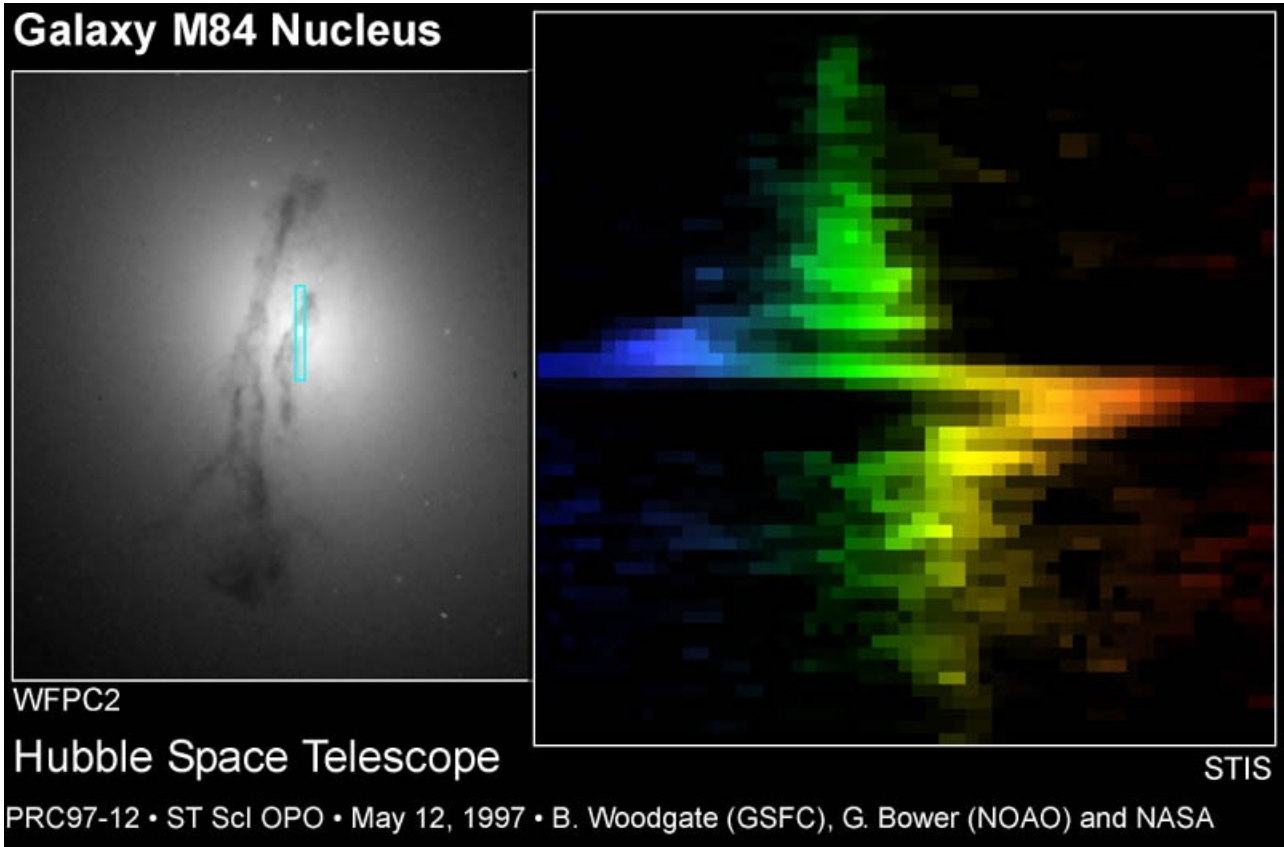


Supermassive Black Holes

- Most large galaxies are believed to have supermassive black holes at their centers (we have found no galaxies without one).
- Largest ones reach 3 billion $M_\odot$ (ours is 3.3 million $M_\odot$, Andromeda's is 20 million $M_\odot$).
- The bigger the galaxy, the larger the black hole. Somehow, galaxies know how big a black hole they must have – this is known as "M-σ" relation.
- But black holes are very small compared to galaxies, there shouldn't be any connection between them. It remains unexplained.

Black Holes Masses

- Black hole masses are measured by the same old Kepler's law.



Believe it or not, black holes are the brightest objects in the universe!

- As gas falls into a black hole, it can turn up to 15% of its rest energy (mc^2) into radiation (stars only do 0.7%, and only in the core).